Assessing Carabid Contribution to Ecosystem Services: Does It Matter If There Are More Beetles?

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In the Spring of 2004, an agronomist (J. Singer) approached several entomologists (R. Hellmich, M. O'Neal, J. Prasifka, and N. Schmidt) about a collaboration to study the pest management benefits of incorporating living mulches in annual crop (corn and soybean) production. Living mulches are cover crops retained during the production of a main crop on the same parcel of land. A living ground cover can provide several benefits, including weed suppression, nutrient recycling, and reduced erosion (Hartwig and Ammon 2002). When compared with conventional production methods, a legume living mulch can fix enough nitrogen to reduce fertilizer requirements and increase yields in the main crop (Ilnicki and Enache 1992). However, living mulches may need to be suppressed to reduce competition with the main crop when water and nutrients are scarce (Echtenkamp and Moomaw 1989, Tharp and Kells 2001, Affeldt et al. 2004). Because living mulches reduce agricultural disturbances and increase vegetational diversity, changes in the community structure of arthropod pests and their natural enemies are likely (Andow 1991). Pest populations, particularly of aphids and lepidopterans, are often reduced by the adding living mulches to an agroecosystem (Costello and Altieri 1995, Vidal 1997, Hooks and Johnson 2004).

We observed a significant impact on several taxa of arthropods when corn and soybeans were grown with a living mulch. A full description of that response will be presented in a future manuscript; here, we focus specifically on the response of ground beetles. Given an anticipated increase in ground beetle activity where a living mulch is present, we investigated to what extent predation would also increase. Although we did not measure the suppression of a specific pest, we used sentinel prey as an index of biological control. We discuss the potential improvement in biological control that occurs in light of the competition between the living mulches and the annual crop.

Establishing and Maintaining Living Mulches

Living mulches in a three-year rotation of corn (Zea mays L.), soybean (*Glycine max* (L.) Merr.), and a forage (the living mulch alone without an annual crop; Fig. 1) were examined in a randomized complete block design. Each phase of the rotation was replicated within a split-plot treatment arrangement with whole plots assigned to corn, soybean, or forage crops. Subplots (3.8 × 18.3 m) comprising nitrogen-fixing mulches of alfalfa (*Medicago sativa* L.) and kura clover (*Trifolium ambiguum* M. Bieb.) were seeded in August 2002 with a grain drill in 0.20-m rows. In 2003, living mulches were allowed to establish, and main crops were first planted in 2004. To promote main crop growth where living mulches were present, a 0.25-m wide herbicide band was applied over the seed row in April. When the living mulch grew above the main crop, additional control of the mulches was accomplished with a rolling stalk chopper (cutting between rows in April, May, and June) and herbicide application (applied over rows in

Fig. 1. Alfalfa as a living mulch in corn (A, 25 June 2004) and soybean (B, 6 August 2004). Competition between the alfalfa and the main crop was apparent (C) throughout the growing season and resulted in a 20-cm reduction in soybean height compared to the no-mulch control. A similar degree of competition was observed for soybeans grown within kura clover (unpublished data).

Fig. 2. Sentinel prey and vertebrate exclusion cages used to estimate predator activity. Cages were 9 cm high and 14.5 cm in diameter. Two cages per treatment pushed into the soil (2.5 cm) were covered with plastic Petri dish lids to reduce disturbance by vertebrate animals and rainfall.

May). Control (no living mulch) split-plots were maintained weed-free with herbicide applications and hand weeding as necessary. Corn and soybean were harvested in October and September, respectively.

Predator Abundance and Feeding on Sentinel Prey

Two pitfall traps in each subplot were used to sample ground-dwelling arthropods. Traps were placed in the center row, inset 6 m from opposite ends of the living-mulch subplots. Once monthly from June through September, pitfall traps were opened for 72 h. Predators were sorted into groups and identified to order (all Arachnida), family (most Insecta), or species (Coleoptera: Carabidae).

Within 1 wk of pitfall trapping, invertebrate predation rates were estimated in each plot. Cages (Fig. 2) were placed around sentinel prey to exclude vertebrate predators. Prey consisted of laboratory-reared European corn borer (*Ostrinia nubilalis* Hübner) pupae (10/cage) that had been previously freeze-killed and glued to sandpaper. After 72 h, pupae were collected and categorized as intact, preyed upon, or missing.

Pitfall trap and sentinel prey data were analyzed with similar split-plot analyses of variance, with one exception. The dependent variable was transformed to the square root of percent predation, with percent predation for a plot calculated as the number of pupae preyed upon divided by the sum of the number preyed upon and intact.

Effects on Carabid Species Abundance and Predation

Carabids accounted for ~60% of the predacious arthropods collected in pitfall traps (data not presented). Analyses of carabid abundance indicated a split-plot effect of mulch treatments (Table 1), with no impact due to crop (whole plot factor).

Just over 2% of the European corn borer pupae were categorized as lost; the percentage preyed upon averaged 51% over all sample periods. During September prey removal rates were >95% with no treatment effects observed (data not presented), therefore averages were calculated from the June through August sampling period (Fig. 3). Combining data across June-August, prey removal nearly doubled when a living mulch was present ($F = 21.6$, df = 2, 6; $P = 0.002$). We did not observe a main crop effect ($F = 1.83$, df = 1, 3; $P = 0.3$) or a crop by mulch interaction ($F = 0.46$, df = 2, 6; $P = 0.7$).

Conserving Ground Beetles: Costs and Benefits

Our results are consistent with previous studies demonstrating potential pest management benefits when a living mulch is incorporated into a production system. Living mulches increased the abundance and diversity of ground beetles and subsequent prey removal within the annual crops (Table 1, Fig. 3). Unlike the ecosystem services provided by more specialized natural enemies or even insect pollination (Kremen et al. 2002), the level of ground beetle-derived benefits may be difficult to quantify fully. Yield reduction can occur from multiple pests that may suffer from ground beetle predation (weed seeds and arthropods). Ground beetles can consume a wide range of prey and, as generalist predators, may play an important role in suppressing pests below outbreak levels.

It is remarkable that we observed a significant response in ground beetle abundance, diversity, and predatory behavior in an experiment using small plot sizes. We anticipate that such benefits would continue and possibly increase when a living

Table 1. Ground beetle abundance and diversity in corn and soybeans grown with a living mulch

	Abundance[a]			Treatment effect	Crop effect
Species	No mulch	alfalfa	kura	*F*-value[b]	*F*-value[c]
Total carabids	44	180	124	22.7**	0.1
Pterostichus permundus	7	33	40	6.6**	0.7
Scarites quadriceps	9	35	28	5.8**	0
Poecilus chalcites	1	51	17	11.4**	1.0
Harpalus pensylvanicus	11	24	14	1.7*	0.1
Bembidion rapidum	7	11	9	0.2	0.4
No. species	10	15	14		

* $P \leq 0.05$, ** $P \leq 0.01$
[a]Number of adult beetles collected in both corn and soybeans within each treatment
[b]df = 2, 15
[c]df = 1, 15

Table 2. Grain yield of annual crops grown with a living mulch

	Yield[a] (bushels/acre)		
Crop	No living mulch	Alfalfa	Kura
Corn[b]	215 a	196 b	190 b
Soybean[c]	64 a	48 b	42 b

[a]Corn yield presented at 15.5% moisture and soybean at 13% moisture .
[b]P = 0.034, LSD = 14.4, df = 2,3.
[c]P = 0.003, LSD = 2.5, df = 2,3.

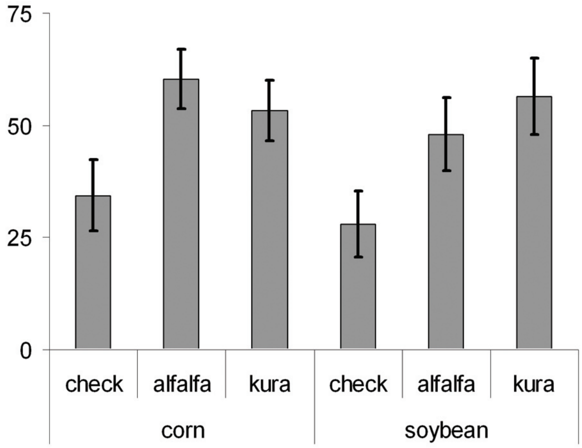

Fig. 3. Seasonal average (± SEM) of sentinel prey removed from annual crops planted into a living mulch. Means with unique letters (capital = corn, lower case = soybean) are significantly different (P = 0.05).

mulch is incorporated into a larger scale production system. However, sentinel prey studies such as ours provide only an index of biological control activity. Methods that provide a quantitative estimate of ground beetle value would be helpful as studies such as this one increase in scale.

Ground beetles and biological control are only one aspect of crop production, and the benefits of ground beetles will need to be examined within the context of the entire cropping system. In our study, a significant yield reduction occurred in both annual crops when grown with a living mulch, with the greatest reduction (30%) occurring in soybean (Table 2). This high degree of competition may reflect the entry of annual crops into vigorous forage stands. In subsequent years as the living mulches experience repeated plantings of corn and soybean, the difference in yield may diminish. The overall value of incorporating living mulches within an agroecosystem may involve multiple environmental benefits that may offset the costs associated with yield production. The costs and benefits of the living-mulch systems will have to be considered in aggregate over several years when assessing living mulches as farm management practices.

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"What is it?" Answer.

A ceratopogonid feeding on the head of a *Ghinallelia brasiliensis* (Dohrn, 1860) (Hemiptera-Heteroptera: Reduviidae: Emesinae) female. Both were collected in the city of Cabo Frio (22° 51' S - 42° 03' W), Rio de Janeiro State, Brazil, in march/2005. The photograph was taken and submitted by Hélcio R. Gil-Santana, Department of Entomology, Oswaldo Cruz Institute, Rio de Janeiro, Brazil. E-mail: helciogil@uol.com.br.

If you have a photograph you would like to submit for consideration as a "What is it?" photo, please e-mail it as a 300 dpi TIFF to the editor at cdarwin@aol.com.